TRANE

engineers newsletter

volume 36–1 • providing insights for today's hvac system designer

water-side heat recovery

Everything old is new again!

from the editor...
In response to an energy crisis and an oil embargo, the 1970's was a decade during which design engineers recovered heat from the chiller's condenser for use in other portions of the building or process. At that time Trane published a number of newsletters and manuals on heat and energy recovery.[1] During the building booms of the 1980's and 1990's interest in energy waned -- hence heat recovery was used less.

As energy costs have again increased, and environmental awareness has come to the industry forefront, use of energy recovery has again increased. (Airside energy recovery was covered in ENEWS-29/5.)[2] Interest in heat recovery from the condensers of water-cooled chillers has also increased. A problem is that many of the people who designed these systems during the 1970's and earlier are retired, so there is unfamiliarity with the systems. This newsletter gives information that should help the engineer properly select equipment, as well as design system configurations and controls to ensure efficient operation.

How is energy recovered?

In any cooling system, heat is transferred from the load location whether the load is a result of space temperature conditioning, dehumidification, or a process. When air conditioning equipment is providing this cooling, several subprocesses are involved:

- Heat is removed from either the space or the process by the evaporator or the chilled-water coil.
- Heat is transferred to a condenser during the refrigeration process.
- Heat is transferred from the condenser to the outdoor air.

For air-cooled systems, heat is generally transferred directly to the outdoor air.

For water-cooled systems, the heat is first transferred to a cooling tower, then to the outdoor air.

An alternative for water-cooled systems is to recover the heat, rather than rejecting it through the cooling tower. This is the focus of this newsletter.

Renewed interest due to…

Energy Costs. In order to efficiently recover heat, there must be simultaneous heating and cooling loads.

Rather than paying to reject heat, building owners can recover heat. This gives a double benefit: Recovered heat reduces purchased heat (and cost) and also reduces the ancillary power necessary to reject the heat. There are also non-economic reasons for utilizing heat recovery.

Energy Codes. Some standards and building codes require condenser-water heat recovery for service water heating (see sidebar). A few applications that meet these criteria are hotels, dormitories, hospitals, correctional facilities, and high-rise condominiums with central-cooling systems.

In addition to code requirements, specific building owners may decide to mandate the standard's use. For example, the U.S. Army Corps of Engineers publication Humidity Control for Barracks and Dormitories in Humid Areas states:

"…Army shall use condenser heat recovery in accordance with ASHRAE 90.1."[3]

ASHRAE/IESNA 90.1-2004:

6.5.6.2 Heat Recovery for Service Water Heating

6.5.6.2.1 Condenser heat recovery systems shall be installed for heating or preheating of service hot water provided all of the following are true:

(a)The facility operates 24 hours a day.

(b) The total installed heat rejection capacity of the water-cooled systems exceeds 6,000,000 Btu/h (1,760 kW) of heat rejection.*

(c) The design service-water heating load exceeds 1,000,000 Btu/h (290 kW).

6.5.6.2.2 The required heat recovery system shall have the capacity to provide the smaller of:

(a) 60% of the peak heat-rejection load at design conditions, or

(b) Preheat of the peak service hot-water draw to 85°F (29.4° C).

Exceptions to 6.5.6.2:

(a) Facilities that employ condenser heat recovery for space heating with a heat recovery design exceeding 30% of the peak water-cooled condenser load at design conditions.

(b) Facilities that provide 60% of their service water heating from site solar or site recovered energy or from other sources.

Exception (a) allows heat recovery for space heating.[4]

*Editor's note: This is about 450 tons (1,580 kWR) of cooling.

Reduced Environmental Emissions. Energy recovery is often considered a sustainable technology. In fact, the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED®) New Construction (NC) version 2.2 document requires, as a prerequisite, compliance with ASHRAE 90.1-2004.

Some building owners perform energy recovery not only to reduce operating costs, but also to reduce emissions to the environment. Lowering emissions is beneficial for a variety of reasons, including the following:

Burning fossil fuels, such as natural gas, increases site emissions. If the job site has already reached the maximum emissions level allowed, recovering heat can satisfy future loads without consuming more fuel on site. This was the case cited by Ralph Cohen in his ASHRAE Journal article "Energy Efficiency for Semiconductor Manufacturing Facilities."[5]

In addition, some locales are considering emissions trading. If such legislation becomes common, trading the emissions credits may be extremely valuable.

Analysis

Accurate analysis of heat-recovery systems is critical. Often there is the temptation to use methods such as Equivalent Full-Load Hours (EQFH) or bin analysis. These methods are too simple, especially when applied to heat-recovery systems. The EQFH method ignores part-load operation of chillers and does not account for simultaneous heating and cooling loads. Bin analyses typically relate load and chiller operation to a particular ambient condition. With internal and solar loads being a significant portion of building load, and the fact that most chilled-water plants employ multiple chillers, the bin-analysis methods are rarely sufficient.

Important program capabilities to consider when using any analysis tool to examine heat recovery include:

- Calculate coincident cooling and heating loads.
- Account for various fuels (for example, so that systems with electric chillers and natural-gas boilers can be modeled).
- Model diverse utility rates, as they may include time-of-day usage and demand charges.
- Accurately model chiller heat-recovery conditions and energy usage.
- Model system configurations (discussed later) that are used in heat-recovery applications.
- If emissions reduction is important, the analysis tool should be able to show reductions in substances such as CO_2, NOx (nitrogen-oxygen compounds), and SO_2 when comparing the heat-recovery alternative with other alternatives.

Some tools that fulfill these requirements include:

- System Analyzer™ and Trace™ 700 Chiller Plant Analyzer: used for high-level scoping analyses. Comparisons can be made in a short amount of time (usually less than an hour).
- EnergyPlus, TRACE, and HAP: full energy-simulation tools that use detailed hour-by-hour calculations to calculate energy consumption, power demand, and related costs. These tools may be used when more precise calculations are necessary.

How hot does the water need to be?

When considering heat recovery, some designs consider high temperatures (140°F or greater) leaving the chiller's condenser. These high temperatures are not necessary and, in fact, counterproductive since they require significant increases in cooling energy, as will be discussed later.

According to the 2004 ASHRAE Systems and Equipment Handbook,

> "For typical buildings, chillers normally provide hot water for space heating at 105° to 110°F (40.6 to 43.3°C)."[6]

Water Temperature: An Example

- A variable-air-volume box is sized to deliver 2,000 cfm (940 Lps).
- The design supply-air temperature is 55°F (12.8°C) and the design space temperature is 75°F (23.9°C).
- The minimum airflow setting is 30 percent, which corresponds to 600 cfm (280 Lps).
- If the cooling load drops to zero, the air must be heated 20°F (11.1°C) to avoid overcooling the space.

As shown in Table 5, to use 105°F (40.6°C) water requires a two-row heating coil. Some people get concerned about the increase in air-pressure drop, and this certainly should be considered—it requires higher design static pressure and fan horsepower. Because the coil air-pressure difference drops quickly as airflow is reduced, the actual fan-energy increase may be small. The fluid pressure drop due to the coil is much larger for the single-row coil. If there are many heating coils, using single-row coils may dramatically increase pumping power.

Table 1. Comparison of one- and two-row heating coils at 105°F entering-fluid temperature

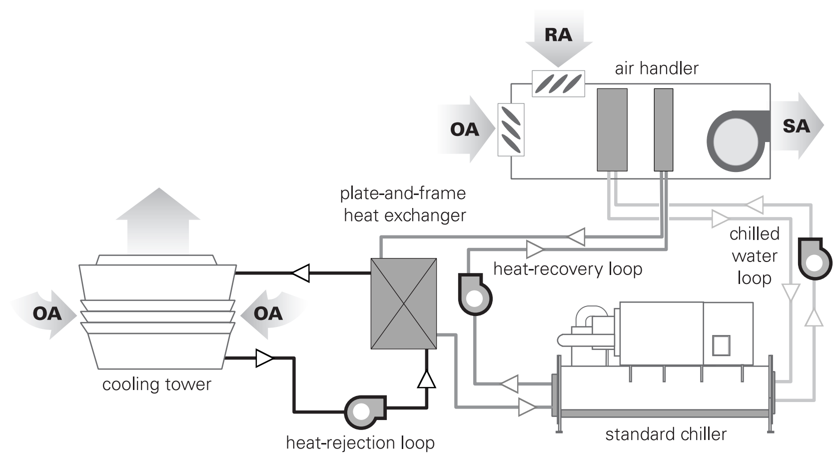
	1-row coil	2-row coil
Entering-water temperature, °F (°C)	113 (45)	105 (40.6)
Coil flow rate, gpm (L/s)	4.33 (0.27)	1.75 (0.11)
Fluid ΔT, °F (°C)	6.02 (3.3)	14.91 (8.28)
Coil fluid pressure drop, ft H_2O (kPa)	10.3 (30.8)	0.21 (0.063)
Air-pressure drop at cooling airflow, inches H_2O (Pa)	0.45 (110)	0.79 (200)
Estimated air-pressure drop at minimum airflow[a], inches H_2O (Pa)	0.04 (10)	0.07 (17)
Coil leaving-air temperature, °F (°C)	75 (23.9)	75 (23.9)

[a] Assumes pressure drop changes with the square of the flow

These are ideal temperatures for heat recovery from any chiller, and can be used in many commercial and institutional applications. The example on the previous page shows how 105°F (40.6°C) water can be used to satisfy loads.

ASHRAE 90.1 (sidebar p.1) also gives some guidance concerning the temperature for service water heating, since it requires service water to be preheated to 85°F (29.4°C). Many service water heating applications use heat-recovery temperatures of 85° to 95°F (29.4° to 35°C).

Figure 1. Condenser-water heat recovery using a plate-and-frame heat exchanger



Heat Recovery types

Heat may be recovered from chillers with only one condenser, or chillers that have an additional heat-recovery condenser. Dual condensers are available in full or partial capacity. This section covers single and dual-condenser chillers. Control options are discussed in a later section.

Single Condenser. A standard chiller can be used in heat-recovery applications.

Most standard water-cooled chillers can provide suitable condenser water temperatures for heat recovery if operated at a slightly elevated refrigerant condensing temperature (e.g. 105°F).

Circulating cooling-tower water through the hot-water coil of an air handler increases the potential for tube fouling. Using a secondary water loop, with a plate-and-frame heat exchanger eliminates this risk (Figure 1). One loop circulates water through the chiller condenser, the plate-and-frame heat exchanger, and the heat-recovery coil. The other loop circulates water through the plate-and-frame heat exchanger and the open cooling tower. In this configuration, the heat exchanger must be sized for the total heat rejection load of the chiller, in case the chiller is fully loaded and there is no heating requirement.

Dual Condenser.

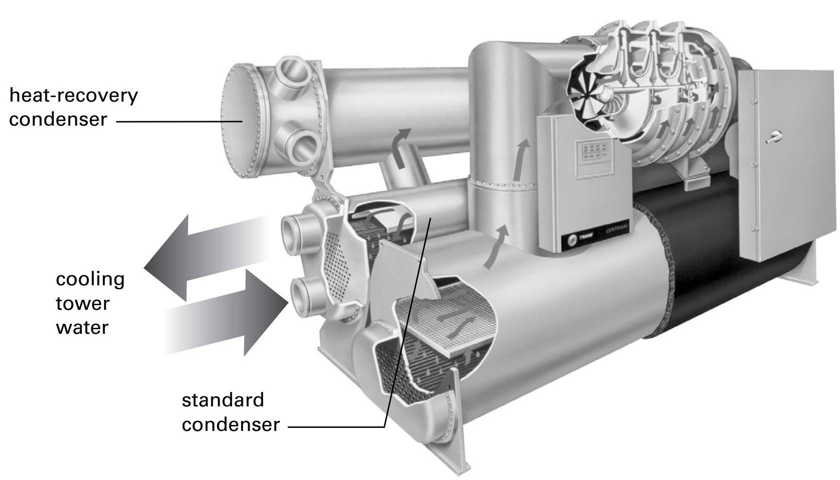
Full Capacity. Some centrifugal chillers allow heat-recovery by using a second bundle. The dual-condenser heat-recovery chiller contains a second, full-size condenser that serves a separate hot-water loop (Figure 2). It is capable of significant heat rejection and relatively high leaving-water temperatures (105° -110°F [40.6° - 43.3°C]). This chiller can also operate as a cooling-only chiller at normal condensing temperature. This type of chiller allows the amount of rejected heat to be controlled, although chiller efficiency is compromised for higher hot-water temperatures.

Cascade

One very specialized, and seldom used, system is referred to as a *cascade system*. As the name implies, temperatures are "cascaded" to produce hot water that cannot be made with only one chiller. Chiller 1 satisfies a cooling load and rejects heat through its condenser. Chiller 2 takes the water from the condenser of Chiller 1 as its cooling load. The heat from Chiller 2 is rejected to a high-temperature heating load. The cascade system amplifies the capability to provide high-temperature water. While sometimes applicable, the higher temperature is often not necessary, and using it can decrease system efficiency.

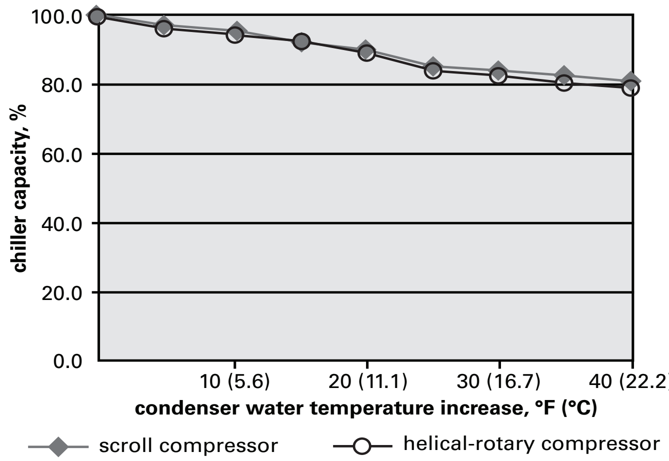
Given the previous guidance on heat-recovery temperatures, a good "rule" to follow is: Use the lowest heat-recovery temperature practical. By using lower water temperatures, not only can the heating load be satisfied, but the chiller's capacity and power draw is not affected.

Figure 2. Dual-condenser heat-recovery centrifugal chiller



Partial Capacity. An auxiliary-condenser, heat-recovery chiller makes use of a second, smaller heat-recovery condenser. It is not capable of recovering as much heat as the full-size, heat-recovery condenser. In addition, the amount of heat rejected from the auxiliary condenser is not controlled — *you get what you get.* Because the leaving-water temperatures for this type of chiller are also lower (for example, 85°F [29.4°C]), the auxiliary condenser is typically used to preheat water. This condenser requires no additional controls and actually improves chiller efficiency by reducing condenser pressure.

Figure 3. Positive-displacement capacity reduction

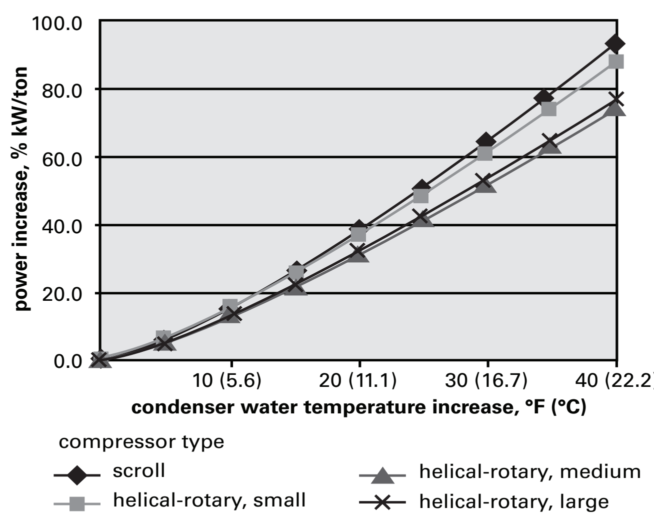


Compressor Type

Heat recovery generally uses less total energy than separate heating and cooling sources, and always reduces the amount of heat that must be rejected. One drawback is that it often requires more chiller energy than a cooling-only chiller, because the chiller operates at an elevated condensing pressure and temperature. To reduce this energy use, recovering heat at the lowest possible temperature is critical.

Positive-Displacement Compressors. A positive-displacement compressor, selected to meet a specific cooling load, will operate at heat-recovery conditions, but at reduced capacity and efficiency. Figures 3 and 4 generically show how two positive-displacement compressor technologies react to elevated condensing temperatures and pressures. These figures are intended for comparative purposes only. Always contact the chiller manufacturer for information on the chiller being considered.

Figure 4. Positive-displacement power increase



For example, producing 140°F (60°C) water increases the kW/ton by 80% or more requires a 20% larger chiller; in contrast, producing 105°F (40.6°C) water results in a 16% increase in kW/ton and only a slight reduction in capacity. The efficiency loss is an important consideration when selecting heat-recovery chillers.

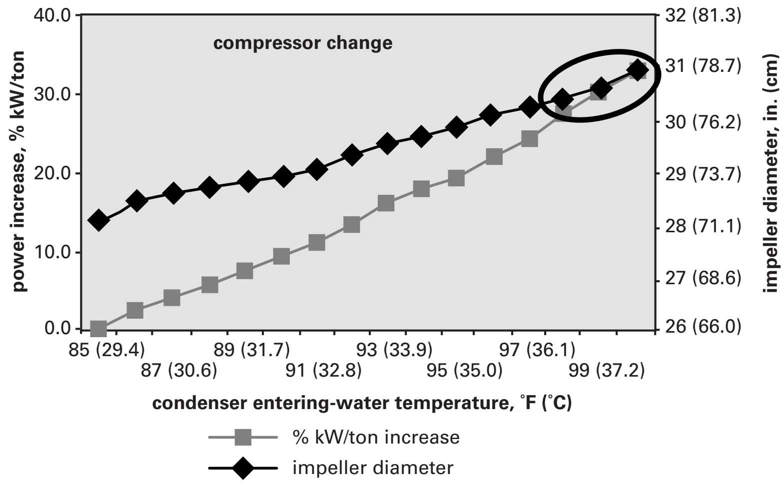
Centrifugal Compressors.
Centrifugal compressors function differently than positive-displacement compressors. Centrifugal compressors use the principle of dynamic compression—which involves converting kinetic energy to static energy—to increase the pressure and temperature of the refrigerant. The affect of increased condenser-water temperature, and refrigerant pressure, differs from positive-displacement chillers.

The same chiller (heat-exchanger shells) can perform at many different condenser leaving-water temperatures if the compressor impeller diameter is allowed to increase. Note that while capacity is maintained for all these selections, the power necessary to achieve the increased pressure differential rises. At some point (in this case, the last three selections circled in Figure 5) the compressor size and cost also increases.

In addition to this increased power draw at the heat-recovery design temperature, a chiller selected for heat-recovery operation is less efficient than a chiller selected at a lower condenser-water temperature, even though everything except the impeller remains the same. This chiller efficiency reduction must be taken into account when energy analyses are performed.

Part Load Operation. At part-load conditions, if the refrigerant differential between the evaporator and condenser is too high, a centrifugal compressor can enter a state called *surge*. Prolonged surge is not good for the compressor and should be avoided. To avoid surge, a heat-recovery chiller should be checked for its ability to unload at the expected heat-recovery, condenser-water temperatures. A compressor with multiple stages has a greater ability to overcome the operating pressure differential in a heat-recovery application and, therefore, maintain stable operation over a wider range of conditions.

Figure 5. Centrifugal chiller power increase



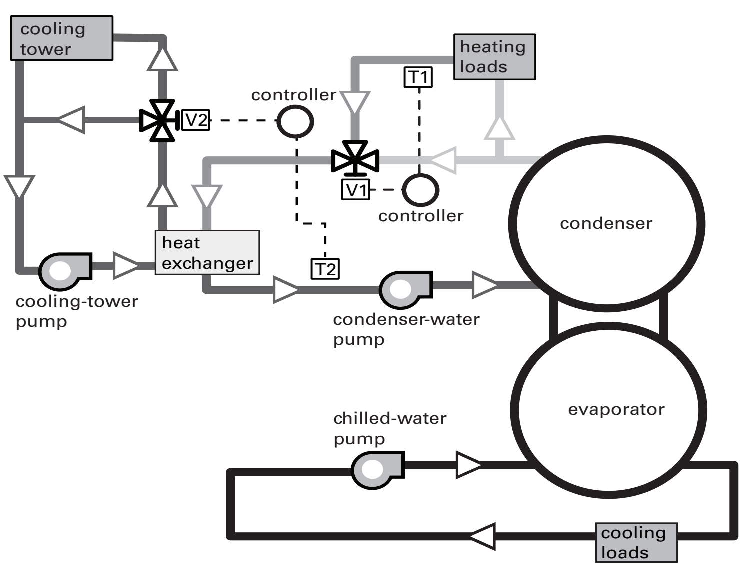
So, to avoid surge conditions centrifugal-chiller heat-recovery capacity should be controlled using the condenser entering-water temperature. This leads us to a discussion on system controls.

Heat Recovery System Controls

Due to the differences in unloading, heat-recovery system controls differ depending on the compressor technology. Heat-recovery control for positive-displacement compressors (screw or scroll) may be based on either entering- or leaving- condenser water temperature. Heat-recovery control for centrifugal compressors should be based on condenser entering-water temperature.

Constant Condenser Entering-Water-Temperature Control. Figure 6 shows a single-bundle condenser using a heat exchanger to separate the tower water

Figure 6. Single-bundle entering-water-temperature control



from the heating loop. The task of the control system is to maintain the condenser entering-water temperature.

The diverting valve in the cooling-tower loop (V2) and the cooling-tower fan modulate to maintain the condenser entering-water temperature (T2).

Another valve (V1) is controlled by the water temperature coming from the heating loads (T1). An auxiliary heat source may be required if the condenser leaving-water temperature is not high enough.

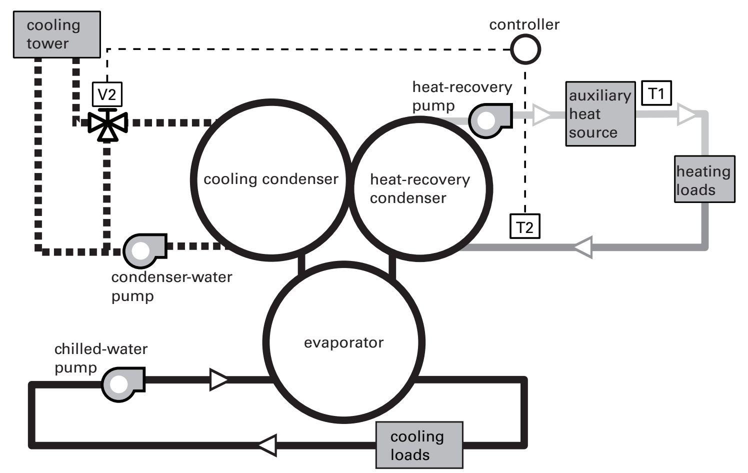
Dual-Condenser Entering-Water Control. A variation of this condenser entering-water temperature control can be used for dual-condenser centrifugal-compressor chillers. In this case (Figure 7), the controlling temperature sensor is at the inlet of the heat-recovery condenser (T2). Many heat-recovery systems use this configuration because it separates the heating loop from the tower loop and requires only simple, understandable controls to function properly.

Constant Condenser Leaving-Water-Temperature Control. A variation of this control (Figure 8) can be used for chillers that can tolerate a constant condenser leaving-water temperature. This is primarily applicable to positive-displacement chillers, however, centrifugal chillers may be controlled in this manner, if care is taken to avoid surge conditions. This strategy attempts to load the chiller sufficiently to maintain the desired condenser leaving-water temperature.

Using this control method, the primary function of the chiller is to satisfy the heating load; a secondary by-product is the chilled water that is produced. This is often referred to as "heat-pump" mode. The chiller is most often piped in a sidestream position (discussed later) because the chilled-water temperature (T3) varies.

In summary, centrifugal heat-recovery chillers should be controlled using condenser entering-water temperature. If the system can withstand elevated chilled-water temperature, centrifugal chillers may be controlled using heat-recovery condenser leaving-water temperature. Positive-displacement chillers can be controlled using either condenser entering- or leaving-water temperature.

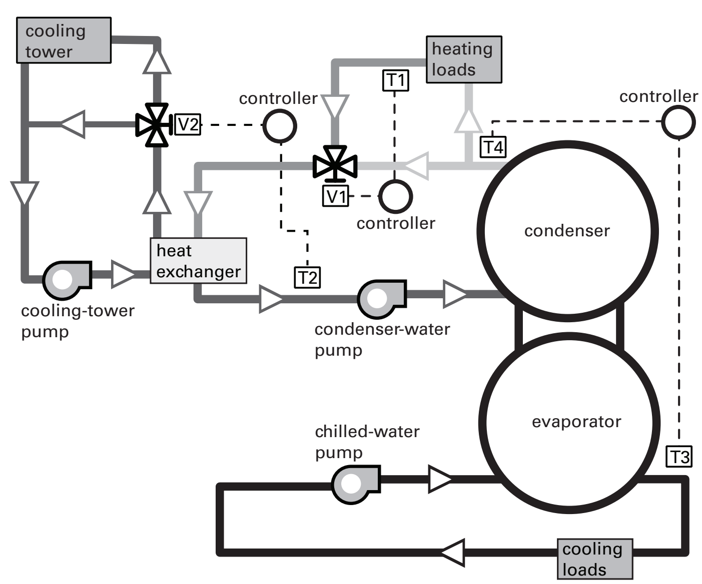
Figure 7. Dual-condenser entering-water-temperature control



Chilled Water System Configurations

Only two system configurations, preferential and sidestream, are covered in this newsletter, since they are used most often in heat-recovery applications. Other configurations are covered in the Trane applications manual, Waterside Heat-Recovery in HVAC Systems.[7]

Figure 8. Single-bundle leaving-water-temperature control



Preferential. When a chiller is located on the load side of the bypass line in a primary-secondary system, it is loaded preferentially because it always receives the warmest return-water temperature (Figure 9). Therefore, when operating, it rejects as much heat as possible. A chiller piped in this location also adds to the chiller-plant flow rate and does not reduce the return-water temperature to other chillers. If the system supply-water temperature is maintained, the chiller may reject more heat than can be used by the heating load.

If multiple heat-recovery chillers are used, proper sequencing can help avoid surge and ensure high heat-recovery condenser leaving-water temperature. The concept is to fully load a cooling-only chiller prior to enabling a heat-recovery chiller. Once enabled, the heat-recovery chiller is loaded at full capacity and therefore much less susceptible to surge. It is also able to produce near-design, heat-recovery condenser leaving-water temperature.

If the heat-recovery chiller can tolerate variable evaporator water flow, a variable-speed drive may be installed on its chilled-water pump. The pump can be controlled to maintain the desired heat-recovery water temperature. When in the preferential-loading position, this allows the chiller to meet the heat-recovery load, maintain the cooling system supply-water temperature, and not reject heat to the cooling tower.

Sidestream

Sidestream. A chiller piped in a sidestream position (Figure 10) can be loaded to any capacity by varying its chilled-water setpoint. When operating, it cools the return chilled-water temperature to the non-heat-recovery chillers.

The non-heat-recovery chiller pumps must supply the entire flow demand of

Figure 9. Preferential loading

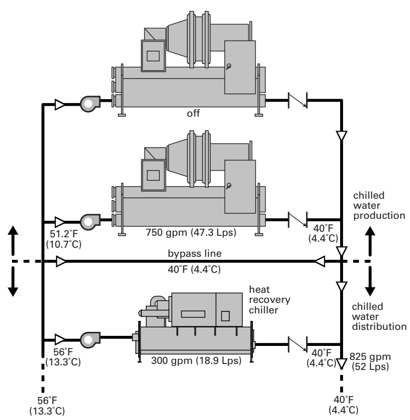
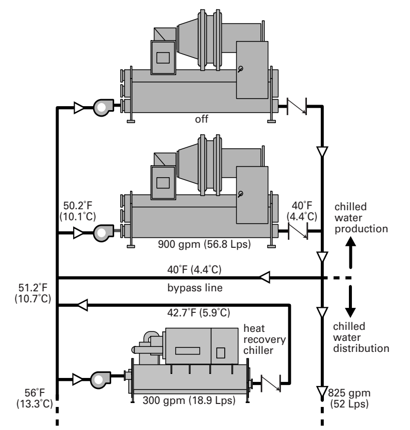


Figure 10. Sidestream



the cooling load. When both heat-recovery and standard chillers are operating, the standard chillers experience a reduced ΔT and will not be able to load to full capacity. This can result in an operating condition where more than one standard chiller is operating to satisfy flow requirements, even though one could meet the load.

An advantage of the sidestream configuration is that the sidestream chiller does not need to produce the design system supply-water temperature. It can produce the exact water temperature necessary to meet the required heating load. This allows the chiller to operate more efficiently because the cooling is produced at a higher chilled-water temperature.

Sidestream is an effective configuration to use for a heat-recovery chiller in a variable primary-flow system.

Summary

Waterside heat recovery is a viable option to address the rediscovered goals of reduced energy costs and environmental emissions. It is used more today than in the recent past.

The following are some general guidelines to consider for your next heat-recovery application:

- Ensure that there are simultaneous heating and cooling loads.
- Select the lowest practical heating temperature to meet the needs, 105°F (40.6°C) is a good starting point.
- Select the proper system configuration —this helps to ensure that the proper amount of heat can be recovered when needed.
- Model the system using the specific chillers, system configuration, control and utility rates.
- Design and control the system properly.
- Educate the chilled-water plant operators so they have a clear understanding of how the system is intended to operate. ■

By Mick Schwedler, manager, applications engineering, Trane. You can find this and previous issues of the Engineers Newsletter at http://www.trane.com/commercial/library/newsletters.asp. To comment, e-mail us at comfort@trane.com.

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